Climatological Solar Radiation Modeling and Mapping

Ray George
National Renewable Energy Laboratory
Golden, Colorado 80401

The National Renewable Energy Laboratory (NREL) estimates surface shortwave radiation for solar energy performance evaluation using a variety of techniques, including surface measurements and models based on surfacemeteorological data. Recently, NREL has begun the use of climatological cloud estimates on a 40 km regular grid to model and map the solar radiation climate (direct normal, diffuse, and global) in areas of the world where surface data do not exist. In this presentation we will discuss the use of the Climatological Solar Radiation (CSR) model, and the climatological data inputs (clouds, water vapor, aerosols, ozone, and albedo) needed for its use.

Currently, the model is being run, and maps created, for international locations of interest. These have included India, the Middle East, North Africa and the Mediterranean, and China, as well as the original study of the U.S., Mexico, and the Caribbean. Total cloud cover data are estimated on a 40 km grid using the USAF RTNEPH (Real-Time Nephanalysis) seven-year climatologies. Opaque cloud amount is parameterized from RTNEPH observed total and layered cloud amounts. Aerosol optical depth comes from a variety of sources including AVHRR and GADS (Global Aerosol Data Set). Precipitable water vapor is from the NVAP 5-year climatologies on a 100 km grid. Albedo is from the Canadian Centre for Remote Sensing (CCRS), ozone is from 11 year TOMS climatologies.

Recently the model has been modified to produce radiation estimates on tilted surfaces. We will discuss the use of the CSR model, input parameters, and output products.

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Seen on a Climate Change Web Site...

"... all models are wrong.

Some models are useful..."

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NREL Solar Radiation Products

■ National Solar Radiation Data Base (NSRDB) -U. S. only, 30 year time series, measured and modeled radiation.

■ NSRDB derived products - Solar collector manual, buildings manual, TMYs.

■ **Solar Radiation Data Grids**

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Uses of a Solar Data Grid

■ Siting Of Solar Energy Systems

■ Performance Evaluation for proposed solar systems at any location

■ Accurate spatial analysis of derived parameters (e.g. PV system payback periods, CO_2 emissions prevented, etc.)

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CSR model

- CSR (Climatological Solar Radiation)
- Written by Dr. Gene Maxwell
- A simplified version of the METSTAT model used to produce the NSRDB

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Inputs to CSR model

Monthly Climatological Means of ...

- Total & Opaque Cloud Cover
- Precipitable Water Vapor
- Aerosol Optical Depth
- Atmospheric Pressure
- Surface Albedo
- Ozone

For each grid cell...

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Products of CSR model

Monthly mean values of...

- Global Horizontal
- Direct Normal
- Diffuse
- Global on a tilted surface

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Data Gridding Strategy

- Use climatological variables by month as inputs.
- Rely on climate and weather community to provide quality long term INPUTS.
- Use manual intervention, bogusing to improve quality of inputs.
- Use surface observations to validate and improve model OUTPUTS.

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Advantages of CSR modeling

- Fairly low compute time
- Allows for QC of a region in a few days
- Leverage big climatological datasets
- Knowledge-based spatial analysis and bogusing of climate maps.
- Statistically linked to surface databases
- Output can be easily used with GIS.

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Disadvantages of CSR modeling

- No direct creation of time series
- Results unrepresentative if inputs unrepresentative.
- Current (RTNEPH) cloud data are weak in equatorial areas.
- Uneven results, satellite vs. surface cloud data.

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CSR model algorithm

■ ... First choose a representative day for each month

■ Then, for each 5 minute time step...
- Calculate Direct Normal
- Calculate Diffuse
- Sum to get Global Horizontal
- Use Perez algorithms to get tilt values.

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Normalized Direct Normal Radiation

$$Kn = T_R \, T_O \, T_{UM} \, T_W \, T_A \, T_{OPQ} \, T_{TRN}$$

Where The Direct Normal Transmittances Are:

■	T_R	for Rayleigh scattering,
■	T_O	for ozone absorption,
■	T_{UM}	for uniform mixed gas absorption,
■	T_W	for water vapor absorption,
■	T_A	for aerosol absorption and scattering,
■	T_{OPQ}	for opaque cloud absorption, and
■	T_{TRN}	for translucent cloud absorption

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Normalized Diffuse Horizontal Radiation:

$$Kd = Ks_{CLS} + Ks_{OPQ} + Ks_{TRN} + Ks_{GRFL}$$

Where The Effective Scattering Transmittances Are:

- Ks_{CLS} for clear skies (Rayleigh and aerosol),
- Ks_{OPQ} for opaque clouds,
- Ks_{TRN} for translucent clouds, and
- Ks_{GRFL} for multiple cloud to ground reflections

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CSR Cloud Inputs - RTNEPH

- RTNEPH = Real-Time Nephanalysis
- Worldwide 40 km grid, polar projection
- 3-hourly data for 7 years (1985-1991)
- Surface data preferred, then satellite
- Twice-daily DMSP polar orbiter.
- Total, Low, Middle, High cloud amounts.

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CSR Cloud Inputs - RTNEPH

- RTNEPH averages for all daylight hours.
- Ratio of high clouds to all clouds.
- Parameterize to get translucent cloud fraction, valid only for surface locations.
- Grid translucent, resample, compute opaque cloud amount for each location.

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Water Vapor Input - NVAP

- NASA/CSU Water Vapor Climatology
- Data on 1X1 degree (100 km) grid
- 5 years data (1988-1992)
- Rawinsonde data, corrected for instrument changes
- SSM/I, TOVS satellite water vapor retrievals

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Aerosol Optical Depth Inputs

- Annual means estimated from any source
- Where direct normal surface data exist, values are backed out using Beer's Law
- AVHRR over water - 1989-1991, seasonal means, 1X1 degree
- GADS - theoretical estimates, 550 km resolution, winter and summer means.

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Ozone, Albedo Inputs

- Ozone from TOMS, 120 km resolution, 11 years (1979-1990)
- Albedo from Canadian Centre for Remote Sensing (CCRS), 280 km.

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(Near) Future Directions

- Calculate Radiation on tilted surfaces, model deployment scenarios.
- Find better sources of aerosol data
- Continue to improve our GIS technology
- Use more recent years of RTNEPH data, OR....
- Switch to different cloud input such as ISCCP

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